Effect of Channel Variations on the Spectral Efficiency of Multiuser Diversity MIMO Systems with Antenna Selection and MRC Reception

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Abstract— The high spectral efficiency or high user data rates from multiuser diversity scheme using MIMO systems with antenna selection and MRC reception is very important development for modern cellular communications. Usually in a service area of such system, the channel type is assumed to remain constant, and in a Rayleigh fading environment such systems are found to provide the highest data rate to a scheduled user. In a service area using multiuser diversity MIMO technology, the users at different locations may not experience the same channel type and hence practically observed data rates differ from the assumed values. We present in this report how the scheduled user data rate suffers if the channel type deviates from Rayleigh to Nakagami-*m* fading in the cellular service area, both for absolute or dedicated SNR scheduling scheme and proportional or normalized SNR scheduling scheme. We explore the loss of user data rates in different received SNR regime 0 dB, 10 dB, and 20 dB, and for different *m* values with different MIMO configurations. We find that at 0 dB per antenna received SNR the loss of user data rates are the highest.

Index Terms— Multiuser MIMO, Spectral efficiency, Absolute SNR scheduling, Normalized SNR scheduling.

I. Introduction

Wireless services are demanding very high data rates day by day. This is not only true for voice and packet data traffic but also because of more and more multimedia traffic being generated from large base of users spread over a service area. Data rates can be increased using MIMO technique under rich scattering environment. Transmit antenna selection with maximum ratio combining receiver (TAS/MRC) scheme in MIMO environment is such a powerful MIMO technique for providing high data rates in download transmission to the users. Fading channel gains as experienced by a user, which is generally has adverse effect on the received SNR and hence the achievable capacity in single user case, is found to be useful in case of multiuser case. It is always possible to find a user in a given time slot which has a strong channel from a base station antenna and the system capacity thus maximized picking that user in that slot. An overview of scheduling scheme in MIMO for advanced systems is reported in [1].

For mobile users in cellular communications, antenna selection with MRC reception is a new development for such high data rate service requirements. As noted in [2], MRC scheme is preferred for many wireless communication systems for its easy implementation. With MRC reception in the user site increases the effective instantaneous SNR of a user which when used by the appropriate transmitting antenna enhances the capacity of the overall system. Picking up the best user with the peak SNR although provides the best system capacity, it happens to be unfair towards users. Hence a proportional fair selection of users based on normalized SNR of the users is also proposed. This technique which provides fair chances to the users also decreases the system capacity. As such this type of techniques is viable when the channel changes sufficiently fast so that the average time any user accesses the channel are satisfactory. In [3] the average access time (AAT) and average access rate (AAR) is studied for multiuser case in Rayleigh fading channel. As the feedback of channel quality by the users always suffers from delay, in [4] a viable rate M-QAM scheme is proposed that is less sensitive to feedback delay. Antenna diversity in multiuser environment for different numbers of transmitting and receiving antennas is reported in [5], where it is shown that transmitting antenna diversity decreases the multiuser diversity compared to single user case. A hybrid multiuser scheduling scheme, which uses both greedy and proportional fair scheduling, is reported in [6] for capacity-fairness tradeoff. The authors in [7] studies multiuser diversity in correlated Rayleigh fading channel and reports that the effect of scheduling and multiuser diversity reduces as the correlation between channels increases. A fair scheduling scheme is proposed in [8] for MIMO system which operates with limited feedback and increases significantly the coverage area, and improves system capacity.

TAS/MRC scheme for Rayleigh fading channel has been studied in [9]. In [10], [11], [12] performance analysis of this multiuser TAS/MRC system over Nakagami-*m* fading channel has been analyzed. We noticed that most of the literatures on TAS/MRC scheme have assumed only one type of fading channel either Rayleigh or Nakagami-*m* for all the users in the system. It may happen that in a service area a group of users is in rich scattered /more faded environment experiencing Rayleigh channel and another group of users in less scattered/faded environment with Nakagami-*m* channel. In such case, with multiuser TAS/MRC system, users experiencing the Nakagami-*m* channel will never be able to access services from base station (BS) because the scheduler in BS will transmit only to that user having the highest SNR. Also, a further concern is the system capacity or user data rate loss when the system MIMO configuration is decided

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assuming Rayleigh faded channel for all users, and whereas it is found practically that the channel gains of users are Nakagami-*m* distributed with a particular m (>1) value. As reported in [13], the Nakagami-*m* distribution fits well with measured channel gains for a variety of fading environments. The practical system capacity loss under such multiuser MIMO TAS/MRC schemes for both absolute and proportional fair scheduling in low, medium and high SNR regime is important for multiuser cellular system designers.

Here in this report, we study how the system capacity or user data rates are effected for a TAS/MRC system with Rayleigh and Nakagami-*m* channel with different *m* (*m*>1) values and for different MIMO configurations. We explore this aspect for both absolute SNR scheduling, also known as greedy scheduling, and proportional fair scheduling, also known as normalized SNR scheduling, in low (0 dB), medium (10 dB) and high (20 dB) SNR regimes.

II. SYSTEM MODEL AND PROBLEM STATEMENT

We consider a multiuser diversity system using TAS/MRC schemes in a single cell with K_u users communicating with a Base station. The base station (BS) has N_t transmit antennas and each receiver has M_r receive antennas . The BS allocates resources to the users and schedules the downlink transmission of data to the users. The BS's each antenna first send pilot signals to all users for channel quality information. The receiver of each user then estimates the SNR value received from each antenna and selects the transmitting antenna with the highest SNR value. Because TAS/MRC is multiuser MIMO system, so the BS uses a feedback channel to acquire the channel state information (CSI). With this feedback channel users feedback their SNR values to the BS. The BS has a scheduler, which selects a user based on a specific scheduling technique such as proportionally fair scheduling technique (PFS) or maximum absolute SNR scheduling technique for sending data. An absolute SNR-based scheduler at the base station selects the best user $l^\bullet$ among all active users as

$$l^\bullet = \arg\max \gamma_l(t) \qquad (1)$$

Where maximization is done from the user set $U = \{1, 2, 3, ..., K_u\}$, and $\gamma_l(t)$ is the instantaneous SNR of lth in time slot t. In PFS technique, the scheduler selects the user whose ratio of instantaneous SNR to its own average SNR is maximum, i.e.

$$l^\bullet = \arg\max \frac{\gamma_k(t)}{\overline{\gamma}_k} \qquad (2)$$

Where maximization is done from the user set $U = \{1, 2, 3, ..., K_u\}$, and $\gamma_k(t)$ is the instantaneous SNR and $\overline{\gamma}_k$ the average SNR of the kth user in time slot t. In this scheduling scheme, the base station selects the user with the largest normalized SNR value. The instantaneous SNR

$\gamma_l(t)$ of the lth user is given by

$$\gamma_l(t) = \overline{\gamma} \sum_{i=1}^{M_r} |\alpha_i^l(t)|^2 \qquad (3)$$

Where $\overline{\gamma}$ is the average per antenna received SNR, and $\alpha_i^l(t)$ represent channel gain for the ith receive antenna of the lth user from a base station antenna under a specific channel fading statistics. The average system capacity between the best transmit antenna of the base station and the best user can be expressed, for the Rayleigh fading channel, as [1]

$$\overline{C} = \frac{Z\log(e)}{\lfloor M_r - 1} \sum_{i=0}^{Z-1} \binom{Z-1}{i}(-1)^i \sum_{t=0}^{M_r-1} \frac{\lfloor t+M_r-1}{(i+t)^{t+M_r}} a_{t,t} P_{t+M_r}\left(\frac{i+1}{\overline{\gamma}}\right) E_1\left(\frac{i+1}{\overline{\gamma}}\right) +$$

$$\sum_{q=1}^{t+N-1} \frac{1}{q} P_q\left(\frac{i+1}{\overline{\gamma}}\right) P_{t+M_r-q}\left(\frac{i+1}{\overline{\gamma}}\right) \qquad (4)$$

Where $\overline{\gamma}$ is mean SNR per receiving antenna, $P_q(.)$ is the Poisson distribution defined by $P_q(x) = \sum_{v=0}^{q-1} \frac{x^v}{\lfloor v} e^{-x}$, and $E_1(.)$ is the exponential integral of first order defined by $E_1(x) = \int_x^\infty t^{-1} e^{-t} dt$ for $x > 0$, and $Z = K_u N_t$.

In a Nakagami-m fading channel, the pdf $f_{\gamma_{l^*}}(\gamma)$ of an instantaneous SNR γ_{l^*} for the best user is given by Equation (5) and Equation (6) , for absolute SNR and normalized SNR based scheduling scheme [14].

$$f_{\gamma_{l^*}}(\gamma) = K_u \frac{\gamma^{m\lambda-1}}{\Gamma(m\lambda)} \left(\frac{m\mu}{\overline{\gamma}}\right)^{m\lambda} \exp\left(-\frac{m\mu\gamma}{\overline{\gamma}}\right).[\mathbb{F}(m\lambda, \frac{m\mu\gamma}{\overline{\gamma}})]^{K_u-1} \qquad (5)$$

$$f_{\gamma_{l^*}}(\gamma) = \sum_{u=1}^{K_u} \sum_{i=1}^{L_u} \frac{\gamma^{m_{u,i}\lambda-1}}{\Gamma(m_{u,i}\lambda)} \left(\frac{m_{u,i}\mu}{\gamma_u}\right)^{m\lambda} \exp\left(-\frac{m_{u,i}\mu\gamma}{\gamma_u}\right).$$

$$P(m_{u,i}) \prod_{j=1, j\neq u}^{K_u} \left[\sum_{i=1}^{L_j} \Gamma(m_{j,i}\lambda \frac{m_{j,i}\mu\gamma}{\overline{\gamma_u}}) P(m_{j,i}) \right] \qquad (6)$$

The average capacity or spectral efficiency can be obtained by numerical evaluation of Equation (7), expressed below, with proper pdf substituted from Equation (5) and Equation (6) [10]

$$\overline{C} = \int_0^\infty \log_2(1+\gamma_l) f_{\gamma_l}(\gamma) d\gamma_l \qquad (7)$$

We consider that all the users in the cellular service area have the same mean SNR per antenna, and experience the

same channel fading type which is characterized by different values of m, $m=1$ characterizing Rayleigh fading channel, and $m>1$ characterizing Nakagami-m channel with different specular components. The different specular components for different m values may be understood as equivalent Rice factor K [15] from the relationship $m = S_m K + m_0$,

where S_m =0.4998528 and m_0 =0.76221, for $m>1$.

We consider two groups of MIMO structures, 1x2-1x6 MIMO and 2x2-2x6 MIMO, to evaluate the performance of TAS/MRC for absolute and normalized SNR based scheduling schemes. We explore the effect on the system capacity of the TAS/MRC MIMO systems when the m value of the channel fading deviates practically from its assumed value of $m=1$, i.e. when the assumed Rayleigh channel deviates practically to Nakagami-m channel. The 1x2-1x6 MIMO structure group, where there is in fact no transmit antenna selection, is considered to compare the performance of the TAS/MRC 2x2-2x6 MIMO systems.

III. Simulations, Results And Discussions

We simulate a K_u =22 user cellular multiuser MIMO systems, where the channel between receive antennas of a user and transmit antenna of the base station is Nakagami-m flat fading, for various integer values of m. To simulate Rayleigh fading channel we put $m=1$. The different MIMO structures with N_t transmit antennas and M_r receive antennas with N_t =1, 2 and M_r =2, 4, 6 are considered with per antenna average receive SNR $\overline{\gamma}$ =0 dB, 10 dB, 20 dB. We find average system capacity of the TAS/MRC MIMO system for each m value with different MIMO structures with different , for absolute SNR scheduling and normalized SNR scheduling. This will show the effect on the system capacity and hence loss in system capacity when the channel deviates from $m=1$ to $m>1$ with integer m in the Nakagami-m
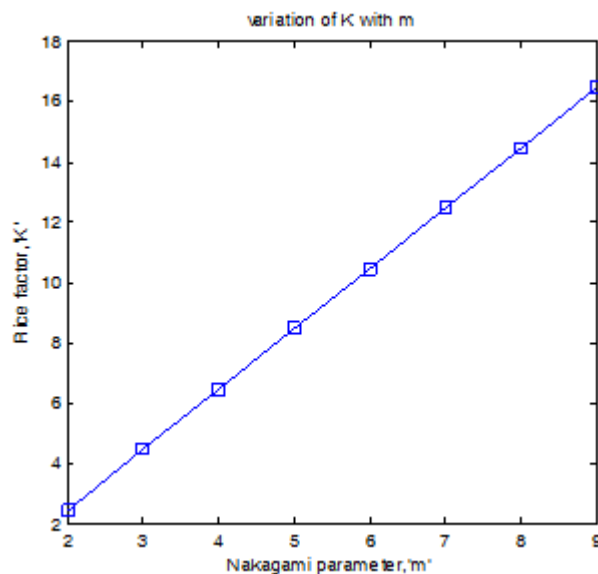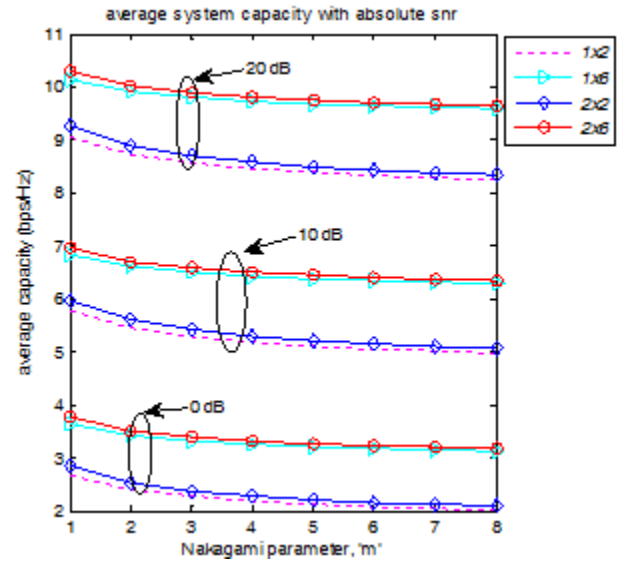

Figure 2. Average capacity of TAS/MRC system using absolute SNR scheduling for different antenna configuration with 0 dB, 10 dB and 20 dB

distribution model for the channel. This is important for system planner for planning a multiuser MIMO wireless communication systems appropriately.

Fig. 1 shows the equivalent Rice factor K when m deviates from $m=0$ to integer $m>0$, where specular signal components with different strengths are expected to decrease the effect of multiuser diversity, as the channel is not now rich scattering. Fig. 2 shows the results of average system capacity for different m values for absolute SNR scheduling with $\overline{\gamma} = 0$ dB, 10 dB, 20 dB. To show the results clearly we plot only for 1x2, 1x6, 2x2, and 2x6 MIMO structures. The results clearly show a decrease of system capacity as the channel deviates from its assumed Rayleigh fading channel. We also see the same trend in case of normalized SNR scheduling in Fig. 3, except the loss is smaller than the absolute
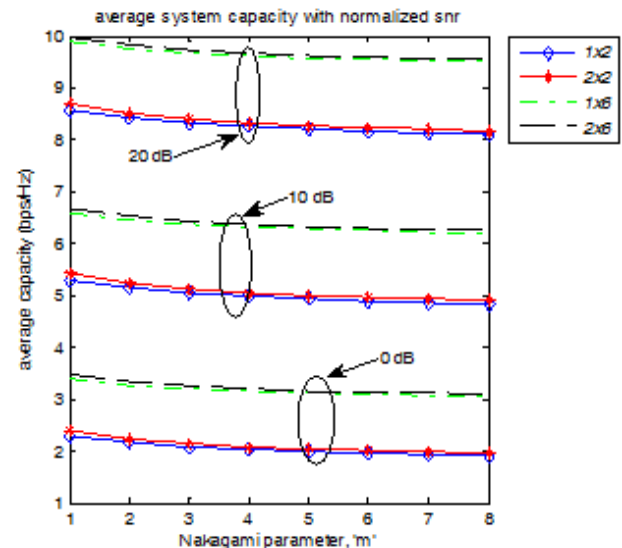

Figure 3. Average capacity of TAS/MRC system using normalized SNR scheduling for different antenna configuration with 0 dB, 10 dB and 20 dB
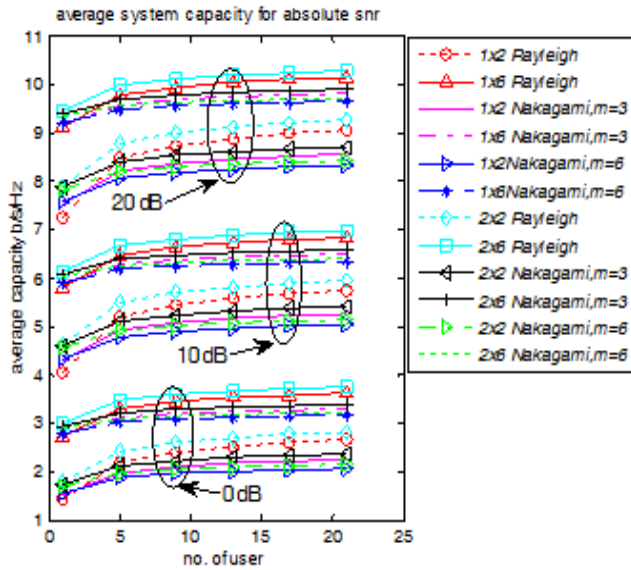

Figure 1. Equivalent rice factor K for different m integer values

Figure 4. Average system capacity (bps/Hz) for different number of users, and for different *m* values and MIMO structures, absolute SNR case
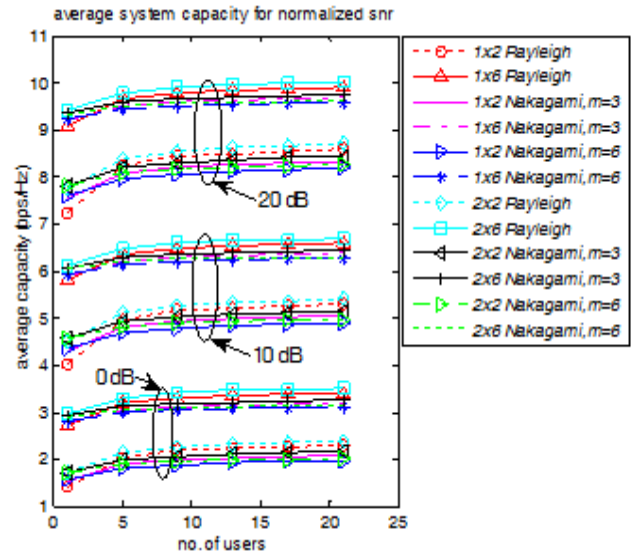

Figure 5. Average system capacity (bps/Hz) for different number of users, and for different *m* values and MIMO structures, normalized SNR case

SNR scheduling. We also show the above results with different number of users in Fig. 4, for absolute SNR scheduling, and in Fig. 5, for normalized SNR scheduling. It is observed that for number of user>1, the average system capacity decreases with deviation from assumed Rayleigh channel fading in the service area.

We calculate the percentage average capacity loss of a MIMO structure in a particular $\overline{\gamma}$ regime, when the assumed channel deviates from the ideal Rayleigh scattering, by the following expression.

Let $\overline{C_R}$ =Average system capacity in Rayleigh fading channel, and $\overline{C_{NG}}$ = average system capacity in Nakagami-*m* fading channel with *m*>1. Then the % average system capacity

loss in bps/Hz is

$$L_{R-NG} = \frac{\overline{C_R} - \overline{C_{NG}}}{\overline{C_R}} x100 \qquad (8)$$
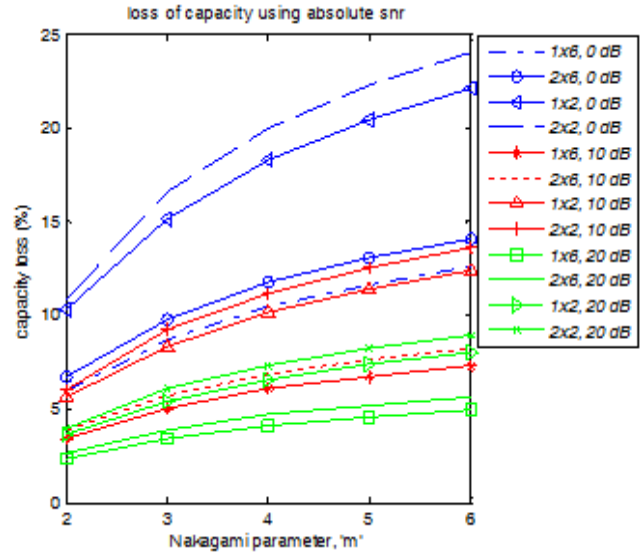

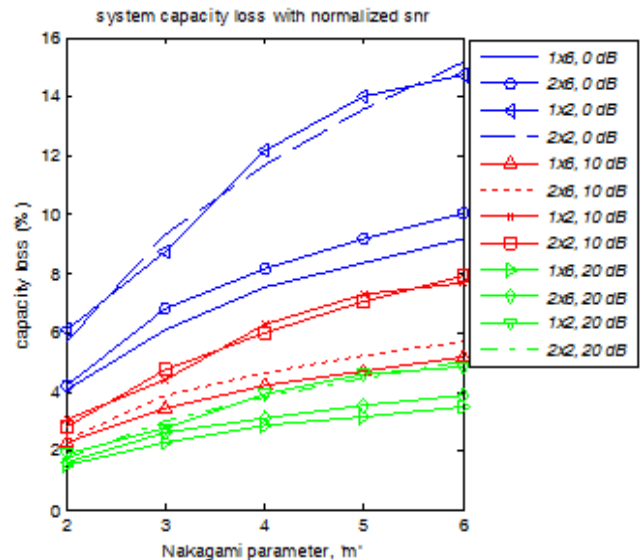Figure 6. %Capacity loss Vs Nakagami parameter *m*, for absolute SNR scheduling

Figure 7. %Capacity loss Vs Nakagami parameter *m*, for normalized SNR scheduling

For comparison of performances under the two scheduling schemes, each TAS/MRC MIMO system is compared with other systems in a particular per antenna SNR regime. We observe from Fig. 6, for absolute SNR scheduling, that for 1x2 and 2x2 MIMO structures, the percentage capacity loss is highest in 0 dB regime, when *m* varies from 2 to 6. The capacity loss varies approximately from 10% to 24% , the 2x2 structure having higher loss. For the same scheduling scheme the smallest capacity loss is incurred by the 1x6 and 2x6 in the 20 dB regime, and it varies from 2.5% to 5% approximately, for the same variation of *m*. In the normalized scheduling scheme, Fig. 7 shows that the percentage capacity loss for 1x2 and 2x2 MIMO structures in 0 dB regime is around 6%

TABLE I. AVERAGE CAPACITY OF TAS/MRC SYSTEM WITH ABSOLUTE SNR SCHEDULING

SNR	m	Antenna configuratio n/Spectral efficiency					
		1x2	2x2	1x4	2x4	1x6	2x6
0 dB	1	2.676	2.845	3.255	3.399	3.636	3.762
	2	2.401	2.536	3.014	3.121	3.421	3.510
	3	2.271	2.373	2.903	2.988	3.319	3.394
	4	2.187	2.278	2.829	2.907	3.254	3.320
	5	2.130	2.212	2.781	2.852	3.212	3.272
	6	2.084	2.162	2.743	2.806	3.177	3.234
10 dB	1	5.773	5.969	6.431	6.590	6.848	6.984
	2	5.449	5.611	6.164	6.284	6.615	6.713
	3	5.292	5.416	6.039	6.136	6.504	6.587
	4	5.188	5.302	5.955	6.043	6.433	6.505
	5	5.117	5.221	5.899	5.982	6.386	6.452
	6	5.059	5.159	5.855	5.929	6.347	6.411
20 dB	1	9.070	9.270	9.738	9.898	10.158	10.295
	2	8.740	8.906	9.468	9.589	9.923	10.022
	3	8.579	8.707	9.341	9.439	9.811	9.895
	4	8.473	8.589	9.255	9.345	9.739	9.813
	5	8.401	8.507	9.199	9.283	9.692	9.759
	6	8.341	8.443	9.155	9.229	9.653	9.717

TABLE II. AVERAGE CAPACITY OF TAS/MRC SYSTEM WITH NORMALIZED SNR SCHEDULING

SNR	m	Antenna configuration/ Spectral efficiency					
		1x2	2x2	1x4	2x4	1x6	2x6
0 dB	1	2.299	2.374	2.963	3.061	3.409	3.487
	2	2.158	2.239	2.824	2.907	3.270	3.341
	3	2.098	2.153	2.767	2.824	3.201	3.248
	4	2.019	2.097	2.719	2.758	3.152	3.202
	5	1.977	2.053	2.683	2.717	3.123	3.167
	6	1.960	2.014	2.647	2.688	3.095	3.137
10 dB	1	5.303	5.396	6.099	6.210	6.599	6.684
	2	5.141	5.244	5.945	6.041	6.449	6.526
	3	5.069	5.138	5.881	5.947	6.373	6.425
	4	4.971	5.071	5.827	5.871	6.319	6.374
	5	4.918	5.016	5.785	5.825	6.287	6.336
	6	4.896	4.967	5.744	5.792	6.256	6.302
20 dB	1	8.589	8.684	9.402	9.513	9.906	9.993
	2	8.423	8.529	9.245	9.342	9.755	9.834
	3	8.351	8.422	9.179	9.248	9.679	9.732
	4	8.249	8.353	9.126	9.171	9.625	9.680
	5	8.195	8.297	9.083	9.124	9.592	9.641
	6	8.174	8.246	9.041	9.089	9.560	9.607

to 15% for m varying from 2 to 6, which is smaller than absolute SNR case. For 1x6 and 2x6 MIMO structures the corresponding losses are around 1.8% to 3.6% in 20 dB regime. Also it is observed that in all cases of MIMO structures and SNR regimes, the normalized scheduling technique incurs less loss as compared to absolute SNR scheduling. For close look to different average system capacities of various MIMO structures, for different m values and in different SNR regimes, we record our simulation results in Table I and Table II, for absolute SNR and normalized SNR scheduling techniques, respectively.

IV. CONCLUSION

We explore in this report the average system capacity behavior of a multiuser cellular system with MIMO structures 1x2-1x6 and 2x2-2x6, in different average per antenna receive SNR regime of 0 dB, 10 dB, and 20 dB using absolute SNR and normalized SNR scheduling techniques. We specifically explored the loss of average system capacity or spectral efficiency for the system when the experienced channel behavior of the users deviate from the assumed or designed channel fading, the rich scattering Rayleigh fading in the service area. Here we assumed that all the users are at the same distance from the base station thus having the same per antenna receive power at 0 dB, or 10 dB, or 20 dB regimes and are also experiencing the same channel fading characteristics. We calculated percentage capacity loss for all the cases of MIMO structures and in different SNR regimes, using both the scheduling techniques, in comparison to the Rayleigh fading channel. We observe that at 0 dB mean SNR regime, the capacity loss is highest for 1x2 and 2x2 MIMO structures, whereas the capacity loss decreases in 20 dB mean SNR regime and is not that significant. It means that those users which are at the periphery of the cellular service area are going to suffer the worst when assumed channel behavior of Rayleigh fading deviates to Nakagami-m fading behavior even for a moderate value of m=6. The user data rates available are assumed to be same as average system capacity of the cellular system.

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REFERENCES

[1] W. Ajib and D. Haccoun, " An overview of scheduling algorithms in MIMO-based fourth-generation wireless systems," *IEEE Network*, vol. 19, no.5, pp.43-48, September/October 2005.

[2] Valentine A. Aalo, T. Piboon gungon, and G. P. Efthymoglou, "Another Look at the Performance of MRC Scheme in Nakagami-m Fading Channels with Arbitrary Parameters," *IEEE Transactions on Communications*, Vol. 53, No. 12, 2005, pp 2002-2005.

[3] Jing J, R. Michael B, William H. Tranter, "Antenna Diversity in Multiuser Data Networks." *IEEE Transactions on Communications*, vol. 52, No. 3, 2004.

[4] Lin Y, M. S. Alouni, "Performance Analysis of Multiuser Selection Diversity," *IEEE Transactions on Vehicular technology*, Vol. 55 No. 6, 2006.

[5] Qian M, Cihan T, "Practical Multiuser Diversity with Fair channel Assignment," *IEEE ICASSP*, 2004.

[6] Lin Y, Ming K, M. S. Alouni, "On the Capacity-Fairness Tradeoff in Multiuser Diversity Systems," ISWSN' 05, 2005.

[7] Behrooz Makki, and Thomas Eriksson, "Multiuser diversity in correlated Rayleigh-fading channels," *EURASIP Journal on Wireless Communications and Networking*, 2012, 2012:38.

[8] Chiung. J. Chen, Li. C. Wang, "Enhancing Coverage and Capacity for Multiuser MIMO Systems by Utilizing Scheduling," *IEEE transactions on Wireless Communications*, Vol. 5, No. 5, 2006.

[9] M. Torabi , D. Haccoun, W. Ajib, " Capacity and outage probability analysis of multiuser diversity in MIMO MRC systems with Transmit Antenna Selection," PaCRIM 2009.

[10] M. Torabi,D.Haccoun,W.Ajib, "On the capacity and bit error rate performance of multiuser scheduling over Nakagami-*m* fading channel," *Signal Processing*, Vol. 91,issue. 11, November, 2011, pp.2487-2496.

[11] C.C.Hung, C.T.Chiang, N.Y.Yen, "Outage probability of multiuser transmit antenna selection/ maximal-ratio combining systems over arbitrary Nakagami-m fading channels," *IET Commun.*, Vol. 4, Iss.1, pp. 63-68, 2010.

[12] Cen Z., Chi Z., Li Y., Vucetic B, "Error performance of maximal-ratio combining with transmit antenna selection in flat Nakagami-m fading channels," *IEEE Trans. Wireless Commun.*, Vol. 8, no.1, January, 2009 , pp. 424–431.

[13] M. Nakagami, "The m-distribution, a general formula of intensity distribution of rapid fading," Statistical Methods in Radio wave propagation, W. G. Hoffman, Ed. Oxford. U. K. Pergamon, 1960.

[14] Mohammad T, David H, Wassam A, "Multiuser Scheduling over MIMO Nakagami-m Fading Channels: Capacity and BER Performance," *Vehicular Technology Conference*, 2009, *IEEE* 69th.

[15] S. Aunt Abbas, Asrar U. Sheikh, "**A** Geometric Theory of Nakagami Fading Multipath Mobile Radio Channel with Physical Interpretations," *Vehicular Technology Conference*, 1996, *Mobile Technology for the Human race*, IEEE 46th, Volume: 2.

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